

February 19, 1880.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The Right Hon. the Earl of Northbrook was admitted into the Society.

The following Paper was read :—

- I. “On some of the Effects produced by an Induction Coil with a De Meritens Magneto-Electric Machine.” By WILLIAM SPOTTISWOODE, D.C.L., P.R.S. Received February 17, 1880.

In the “Philosophical Magazine” for November of last year I gave an account of a mode of exciting an induction coil by the direct application of one of M. de Meritens’ alternating machines, without the intervention of a contact-breaker or the use of a condenser. The experiments of Professor Dewar on the arc furnished by the machine itself, on its spectrum, and on its behaviour in respect of electrolysis described before the Royal Society (see “Proc. Roy. Soc,” vol. xxx, p. 170), have led me to think that an account of some of the peculiarities in the induced discharge, to which the machine gives rise, might be acceptable to the Society.

And, first, as regards the secondary discharge in air. It was mentioned in the paper first quoted that the spark produced by this machine presented an unusually thick yellow flame, and that it was accompanied by a hissing noise different from that commonly heard with a coil excited by a battery. As the machine gives alternate currents, the secondary discharge presents sparks of equal strength in both directions, and the general appearance to the eye is symmetrical in respect of both terminals. The spark was observed in a revolving mirror, first in a vertical and secondly in a horizontal direction. The discharge, although apparently continuous, was immediately seen to be intermittent, with a period in unison with that of the machine. Tongues of flame, leading alternately from one terminal and from the other, crossed the field of view. The length of spark first used (vertically) was about half an inch. When the length was increased to about two inches, the discharge being vertical, flashes or bands of continuous light were seen to traverse the field of view in diagonals of low slope (*i.e.*, nearly horizontally), showing that there were masses of heated matter passing

from time to time at moderate velocity between the terminals. From the known period of the machine, and the number of the discharges crossed by these flashes in their passage from terminal to terminal, it was calculated that the time of passage was about $\cdot 03$ of a second. Occasionally there was a still brighter flash or meteor, which similarly traversed the field, but with a velocity apparently of about double that of the others.

When the discharge was set horizontally, similar phenomena were seen; but at a distance about midway between the two terminals, the flames appeared to meet, and at their point of meeting they showed continuous luminosity throughout. When the flame was blown aside, there appeared occasionally, and at rather long intervals, the true spark, evinced by an irregular bright line, reaching from one terminal to the other.

On observing the discharge in air attentively, it was noticed that whenever a true spark passed vertically its passage was marked, as usual, by an irregular bright line when its path was outside the aureola or flame, but by a similar dark line when its path was within the aureola.

With reference to this phenomenon, it may be observed, in the first place, that in every coil discharge the true spark is always anterior to the aureola, which, in fact, immediately follows it. The true spark of each discharge taken by itself will, therefore, always appear as a bright line. It, however, sometimes happens, as mentioned above, that in the succession of discharges produced by the present method, the flame or aureola of one discharge lasts, at least over part of its length, until the next takes place. When this is the case, the spark of the succeeding discharge will pass partly through air, as usual, and partly through the flame which has lasted over from the preceding discharge. This part of its path will be through a conductor, which may be so far better than the air, as to allow the spark to pass in a non-luminous condition. The phenomenon noticed by Mr. De La Rue, viz., the sudden expansion of a gas at the instant of the passage of an electric discharge through it, may then take place, and the displacement of the flaming gas over that part of the path may give rise to the appearance of the dark line within the area of the aureola. The remaining part of the path, if any, will be bright. It is, however, further to be noticed that the true spark, or those portions of it which are bright, always appears to lie outside, and never within, the aureola. This may arise from the fact that on the extinction of a flame the portions of space immediately outside are for the moment the hottest and most conductive, and that the next spark will consequently choose a path really outside the contour of the flame just extinguished. And as the successive flames do not differ materially in size or shape, the bright spark will appear always to lie outside the flame.

The spectrum of the secondary spark was then examined with terminals of various metals.

Aluminium.—The spectrum showed a faint continuous background with the yellow sodium lines, and faint oxide of aluminium lines. This was with a spark of half an inch. But although the spark was subsequently lengthened, no difference in the spectrum was perceived excepting that the continuous background was rendered more bright.

It would seem that these appearances are due to some such process as the following:—The heat due to oxidation, added to that of the discharge, is sufficient to volatilise the oxide of aluminium; but that in its passage across the interval between the terminals, the oxide becomes so cooled that it gives a continuous spectrum. When the spark was lengthened, the oxide, although perhaps at first more heated than with the shorter spark, had more time to cool.

Magnesium.—In this, as in the former case, we have a faint continuous spectrum as a background, on which were seen the *b* group of magnesium lines. One other line in the blue occasionally flashed out, but was not permanently present. There was also a faint trace of the oxide spectrum. The contrast between the cases of aluminium and magnesium, in respect of the prominence of the oxide, or of the true metallic spectrum, is doubtless due to the fact that in the former case the oxide, and in the latter the metal, is the one which is more easily vaporised. On sending a blast of air on the discharge, the blue line always disappeared; the current of air having lowered the temperature so far as to prevent the vaporisation necessary for its production.

When the spark between magnesium terminals was made to pass through hydrogen, the characteristic lines of hydrogen were seen, apparently owing to a rise in temperature. This, as mentioned below, does not occur with carbon poles.

Platinum.—With terminals of this metal the spectrum was mainly continuous, with the addition of the ubiquitous yellow sodium lines. When the spark was short a few bands were faintly visible, some apparently those of nitrogen, and others in the blue and violet belonging to the oxide of platinum. When the spark was lengthened, these bands disappeared, and nothing but the continuous spectrum (with the D lines) was visible.

It appears from these experiments that the application of the de Meritens machine to the induction coil furnishes us with the means of isolating certain lines of the metallic spectrum from the rest. It has, in fact, enabled us to reduce at pleasure the spectra of aluminium, of magnesium, and of platinum, to their most persistent lines; precisely as had already been noticed as occurring by natural processes in the cases of sodium and of calcium. As a general rule, when the spark is shortened, the metallic, or the oxide, lines come out, according as the

one or the other is more easily vaporised; and when it is lengthened they disappear.

From this we may conclude (1) that the discharge which we have been examining, is a real flame with metallic particles passing between the terminals in a solid condition; and (2) that in general the temperature is comparatively low, *i.e.*, that it is insufficient to cause any considerable vaporisation. This is notably the case when the arc is long, and when the matter thrown off from the terminals has sufficient time in its passage to cool.

The spark was then tried between carbon terminals in atmospheres of hydrogen and of carbonic acid. In none of them did the spectrum show any gas lines; but with hydrogen there were faint traces of the hydrocarbon group in the green. In this respect the spark differs from the discharge direct from the machine, inasmuch as the latter gives some of the hydrogen lines in hydrogen and carbon lines in carbonic acid.

When magnesium terminals were used in an atmosphere of hydrogen, the yellow sodium lines, the blue and green magnesium lines, and the red line of hydrogen were visible near the terminals, with a continuous background.*

When the spark was discharged in a magnetic field, known phenomena were reproduced, but owing to the thickness and mass of the flame and the extraordinary strength of the magnetic field, they were exhibited in a state of great splendour.†

When the spark passed in an equatoreal direction the whole flame was spread out in an equatoreal plane, in which heated masses might be seen revolving in one direction or in the other in the neighbourhood of each of the magnetic poles. To give some idea of the actual appearance, it may be mentioned, that a symmetrical spindle-shaped discharge, 15 millims. in length and 3 millims. in thickness, was spread out by the magnet into a disk of about 15 millims. in diameter and 1 millim. in thickness. When the spark passed in an axial direction, or when the poles themselves were made the terminals, the phenomena described in my paper "On an Experiment in Electro-Magnetic Rotation" ("Proc. Roy. Soc.," vol. xxiv, p. 403) were reproduced.

Whatever was the direction of the spark, the resistance due to the magnetic field was such as to extinguish the discharge, provided that

* When the same discharge was effected in a magnetic field, the only change observed was that the lines became slightly fainter. There was some reason to think that, at the moment of making the magnet current, the lines became decidedly brighter, and that they lost their brilliancy if that current was maintained. But this, perhaps, requires further examination.

† Through the kindness of the authorities of the Royal Institution, Faraday's great electro-magnet, excited by the Siemens machine, was placed at my disposal.

the striking distance was near the limit that it could attain when no magnetic field was present. If a plate of glass was interposed between the poles of the magnet (which were still used as terminals) the yellow flame disappeared, and the spark divided itself into numerous ramifications of true sparks which found their way round the edges of the plate. As soon as the magnet was excited the resistance in the field became so great as to exceed that of the glass plate itself, and the plate was pierced.

Professor Dewar was good enough to measure the efficiency of the secondary discharge, by taking an inch spark in a glass bulb placed in the centre of a calorimeter, in the same way as he had already measured the efficiency of the intermittent current direct from the machine. The former amounted to about 430 gramme-units per minute, while the latter had been found to be 6,000 per minute. The relative efficiency may, therefore, be taken at about 1 : 15. And as the machine was giving about 300 currents per second, this would give for the secondary

$$430 : 60 \times 300 = \cdot 023 \text{ unit per discharge,}$$

and for the primary

$$6000 : 60 \times 300 = \cdot 3 \text{ unit per discharge.}$$

The results in the case of the secondary discharge may not perhaps possess any great degree of accuracy ; but, in the absence of any other information on the question, they may serve to indicate the general scale of magnitude by which the coil discharge is related to that of the machine.

Leaving the subject of the spark from the induction coil, one of the most remarkable effects produced by this machine was the illumination of vacuum tubes by the currents taken simply from the machine. A small sphere of about two inches in diameter, with an air-vacuum, and having two parallel straight terminals reaching nearly across the sphere and about half an inch apart, was (after the first attempt, when there was some difficulty in getting the discharge to pass) readily illuminated. Owing to the alternate currents, both terminals were of course surrounded with the usual blue halo. When the speed of the machine was reduced, the discharge through the tube was not maintained, showing that only that part of the current from the machine which possessed the highest electromotive force, and perhaps also the greatest strength, was sufficient and was therefore actually used for the purpose. As this was apparently only a small fraction of the whole current, we may herein find an explanation of the fact that, compared with the effect from the induction spark, the illumination was moderate, and the heating insignificant. It would perhaps not be easy to establish an accurate comparison between this and other sources of electricity ; but some idea may be conveyed by the fact

that, from experiments made with this tube with Mr. De La Rue's chloride of silver battery on a former occasion, and quite independently of the present question, it was estimated that a current having an electromotive force of 400 volts was necessary to effect a discharge.

Other tubes were tried, and were illuminated in the same way.

When the tube was placed in the magnetic field, the discharge underwent the modifications described by Plücker, by Hittorf, and by others. But it may be mentioned as a result of the extraordinary strength of the field here employed that, whenever the tube was so placed that the direction of discharge made any considerable angle with the lines of magnetic force passing through it, the discharge was completely extinguished. When the tube was removed to a weaker part of the field, the discharge reappeared distorted in form, and altered in colour, in a manner known to those who have experimented in this direction.

February 26, 1880.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

- I. "On the Solubility of Solids in Gases." By J. B. HANNAY, F.R.S.E., F.C.S., and JAMES HOGARTH, F.C.S. Communicated by Professor G. G. STOKES, D.C.L., LL.D., Sec. R.S. Received February 14, 1880.

The research which we now have the honour of submitting to the Royal Society, and of which a preliminary notice was published in the Society's Proceedings,* was instituted with the view of throwing some further light upon what Dr. Andrews calls the "critical state" of matter. In his famous Bakerian lecture, after a very careful discussion of the question, Dr. Andrews says:† "Carbonic acid at 35·5° C., and under a pressure of 108 atmospheres, stands nearly midway between the gas and the liquid, and we have no valid grounds for assigning it to the one form of matter any more than to the other."

* "Proc. Roy. Soc.," vol. xxix, p. 324.

† "Phil. Trans.," 1869, p. 588.